

Table 10 Inside the “box” largest field strength (DTx active) site percentages by transmitter

DTx Transmitter	CH 33		CH 12		CH 65		Units
	30'	15'	30'	15'	30'	15'	
A 16 Court Street Gap Filler Tx #1	36	30	43	40	50	51	sites
	89	89	83	83	86	87	sites, total
	40.4	33.7	51.8	48.2	58.1	58.6	%
B 95 Evergreen Gap Filler Tx #2	6	8	6	6.0	19	19	sites
	89	89	83	83	86	87	sites, total
	6.7	9.0	7.2	7.2	22.1	21.8	%
C 730 Linden Gap Filler Tx #3	7	6	7	6.0	9	10	sites
	89	89	83	83	86	87	sites, total
	7.9	6.7	8.4	7.2	10.5	11.5	%
D Bishop Ford High School Gap Filler Tx #4	5	6	8	9.0	8	7	sites
	89	89	83	83	86	87	sites, total
	5.6	6.7	9.6	10.8	9.3	8.0	%
E Empire State Building ESB Tx	35	39	19	22.0	N.A.	N.A.	sites
	89	89	83	83	N.A.	N.A.	sites, total
	39.3	43.8	22.9	26.5	N.A.	N.A.	%

OUTDOOR DTx SERVICE EVALUATION

This section deals with the evaluation of *outdoor* reception (“within the box”) via a directional receive antenna with DTx inactive or active at either 30’ AGL or 15’ AGL. Successful DTV reception (i.e., service), as described in the MTVA field test plan, is defined as 3 burst error “hits” or less in a 3-minute viewing window. Two 5G receivers (NTIA-compliant D/A converter boxes) from different manufacturers were used in the testing (generically referred to as Rx1 and Rx2), and reception data for *each* receiver at every test site was measured and recorded since there is no guarantee that they will both perform identically in the field in all propagation environments.

Table 11 contains the results for outdoor DTV service site statistics. First, notice that with DTx *inactive* (i.e. DTx turned OFF), DTV service was observed to be very high already (89% - 93% on both CH 33 and CH 12) considering both DTV receivers and both receive antenna heights. In other words, there were very few outdoor test site reception failures. Of course, this is not surprising since the *peaked* signal field strengths reported in the last section were relatively large, and with the *directional* outdoor receive antenna at 30’ AGL and 15’ AGL, multipath is somewhat mitigated. Ultimately, the true test for New York City is indoor reception, which will be discussed later in this report.

A primary goal is to determine whether DTx technology *helps* DTV reception for a large percentage of test sites that either have weak signals or very poor quality signals (e.g., multipath) or both. However, another valid issue is to determine if DTx transmission *hinders* DTV reception in overlap regions where DTV service already exists without it.

With DTx *active* (i.e., DTx ON), the percentage of successful reception at 30’ AGL *increased* by only 9% (Rx1 and Rx2) on CH 33. Similarly, successful DTV reception *increased* by only 6% (Rx1 and Rx2) at 30’ AGL on CH 12. On one hand, these percentage increases are not very compelling, yet on the other hand they must be viewed in light of the fact that DTV service was already very good to start with *before* the DTx was activated.

An interesting phenomenon occurred at 15’ AGL testing. DTV service at the lower antenna height was slightly degraded compared to 30’ AGL, as one might expect. However, as the multipath became more severe at the *lower* antenna height above ground level, the differences in receiver performance became more apparent as Rx1 showed advantages over that of Rx2. For example, CH 33 service improved by almost 2.5% for Rx1 but degraded by almost 3% for Rx2. For CH 12, there was an improvement of more than 8% for Rx1 but only an improvement of about 2% for Rx2. The service differences between the two consumer receivers are obviously related to the level of equalizer performance in each 5G DTV receiver.

However, it should be noted that the absolute differences in DTV service among *all* of these various scenarios (DTx ON/OFF, 30’/15’, and CH 33/12/65) is relatively small, with service values in the very respectable range of 84% - 100%. **Table 11** also shows the statistics regarding the number of sites that got better, stayed the same, and got worse. Note the largest percentage of sites (85% - 92% across all scenarios) represents DTV service that did *not* change with active DTx, which leads to the conclusion that a vast majority of the sites continued to have successful *outdoor* DTV reception in Brooklyn.

Therefore, a major observation from this data analysis is that the DTx network had very little effect (good or bad) on short-term DTV service for outdoor reception with peaked signals at both 30' AGL and 15' AGL. While this may not be surprising, it is a good result under the Brooklyn test conditions (which started out with good DTV service).

In the special case of CH 65 that had no "main" ESB transmitter, a high percentage of sites (87% - 94% at 30' AGL and 84% - 93% at 15' AGL) had DTV reception with only four 1 kWatt low-power gap filler transmitters. This leads to the conclusion that DTV service on upper UHF channels (ultimately limited to CH 51 after the full-service DTV transition is complete) is possible with strategically-placed synchronized low-power transmitters and no single high-power DTV transmitter on ESB.

Table 11 Inside the "box" DTV service site percentages with antenna adjusted for peak signal strength.

DTx Status	CH 33				CH 12				CH 65				Units
	30'		15'		30'		15'		30'		15'		
	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	
DTx OFF	82	81	83	80	77	76	74	74	N.A.	N.A.	N.A.	N.A.	sites
	90	90	90	90	83	83	83	83	N.A.	N.A.	N.A.	N.A.	sites, total
	91.1	90.0	92.2	88.9	92.8	91.6	89.2	89.2	N.A.	N.A.	N.A.	N.A.	%
DTx ON	90	85	85	77	80	77	81	76	82	76	81	73	sites
	90	90	90	90	83	83	83	83	87	87	87	87	sites, total
	100.0	94.4	94.4	85.6	96.4	92.8	97.6	91.6	94.3	87.4	93.1	83.9	%
Better Service	8	8	5	5	5	5	9	7	N.A.	N.A.	N.A.	N.A.	sites
	90	90	90	90	83	83	83	83	N.A.	N.A.	N.A.	N.A.	sites, total
	8.9	8.9	5.6	5.6	6.0	6.0	10.8	8.4	N.A.	N.A.	N.A.	N.A.	%
Same Service	82	78	82	77	76	74	72	71	N.A.	N.A.	N.A.	N.A.	sites
	90	90	90	90	83	83	83	83	N.A.	N.A.	N.A.	N.A.	sites, total
	91.1	86.7	91.1	85.6	91.6	89.2	86.7	85.5	N.A.	N.A.	N.A.	N.A.	%
Worse Service	0	4	3	8	2	4	2	5	N.A.	N.A.	N.A.	N.A.	sites
	90	90	90	90	83	83	83	83	N.A.	N.A.	N.A.	N.A.	sites, total
	0.0	4.4	3.3	8.9	2.4	4.8	2.4	6.0	N.A.	N.A.	N.A.	N.A.	%

Taking the analysis to the next level, not only is it important to measure DTV service, which often is described as either "all good" or "all bad" due to the digital *cliff effect*, it is important to determine how "close" to the digital cliff the service was at each test site. This is important since these field tests are considered *location* variability tests since a large statistically-relevant number of sites are visited for a short time period. Therefore, *time* variability is not being measured, and long-term signal variations (i.e., dynamics) are not being considered. One means of assessing reception reliability is to measure margin to the threshold of visible errors for *each receiver* at each test site. Margin is defined in the MTVA field test plan as the amount of attenuation prior to the truck preamplifier that can be inserted before DTV service is lost. This simulates signal fading, and indicates the amount of signal fading that can be tolerated before data errors occur that are displayed in the video (and heard in the audio). Note that this margin test does *not* indicate the effects of fading of the *desired* channel alone, as might be the case in practice. In reality, this test decreases, in a broadband manner, *all* of the incoming signals, including any potential adjacent RF channel interferers, thus keeping the relative interference D/U ratios constant. However, this margin test *does* bring the multipath-impaired desired DTV signal closer to the truck's noise floor (as determined by the truck's preamplifier) until threshold of errors is reached, and thus provides some measure of margin overhead at a given test site for a given set of propagation and reception conditions (i.e., CH 33, CH 12 or CH 65, 30' AGL or 15' AGL, DTx OFF or DTx ON).

Table 12 contains the margin site statistics and Table 13 contains the margin site percentages. Note that *without* DTx, the average margins (not SNR values) at 30' AGL for both receivers was greater than 23 dB (CH 33) and greater than 20 dB (CH 12), while they were about 3 dB lower at 15' where the signal levels were slightly lower and the multipath-induced noise enhancement may have been slightly worse. These are very respectable margin numbers, especially for DTx inactive. When DTx was activated, the average margins at 30' AGL increased by about 7 - 9 dB (CH 33 and CH 12), and increased at 15' AGL by 4 - 9 dB (CH 33 and CH 12), again presumably due to increased signal strength but also possibly by reduced naturally-induced multipath since a closer transmitter may have been the source of the largest signal to the directional receive antenna. Remember that the receive antenna is repositioned for the maximum signal level when the DTx system is activated, which may be at a different angle than when DTx is inactive. It is believed that outdoor reception margins greater than 25 dB may increase indoor DTV reception statistics, *possibly* accommodating lower gain receive antennas at lower levels above ground level and building penetration loss.

The CH 65 DTx network was only tested with DTx ON since no CH 65 transmitter existed on ESB. On the average, it typically provided 19-23 dB of margin (for Rx1 and Rx2 at both 15' AGL and 30' AGL), indicating that any upper UHF channel may be useful for outdoor reception in Brooklyn, and that it might be useful for indoor reception with a DTx network containing only 1 kWatt low-power distributed transmitters and no large ESB transmitter.

Table 12 Inside the "box" DTV margin statistics with antenna adjusted for peak signal strength.

DTx Status	CH 33				CH 12				CH 65				Units
	30'		15'		30'		15'		30'		15'		
	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	
DTx OFF	23.6	23.1	20.0	19.9	20.1	20.1	16.9	17.0	N.A.	N.A.	N.A.	N.A.	dB (ave)
	24.5	24.0	20.0	20.5	20.0	20.0	18.0	17.0	N.A.	N.A.	N.A.	N.A.	dB (med)
	11.8	12.5	10.5	11.3	10.0	10.2	9.6	9.6	N.A.	N.A.	N.A.	N.A.	dB (std dev)
DTx ON	30.9	30.3	25.8	24.3	29.7	28.9	26.4	25.1	22.5	21.6	19.7	18.8	dB (ave)
	32.0	31.5	26.5	26.0	32.0	32.0	26.0	26.0	23.0	22.0	20.0	20.0	dB (med)
	9.8	11.3	11.1	13.0	11.2	12.5	10.7	12.7	10.8	12.0	10.0	11.5	dB (std dev)
Change in Margin with DTx	7.3	7.2	5.8	4.4	9.6	8.8	9.5	8.1	N.A.	N.A.	N.A.	N.A.	dB (ave)
	2.5	3.0	2.0	0.0	8.0	8.0	8.0	7.0	N.A.	N.A.	N.A.	N.A.	dB (med)
	13.0	14.1	11.1	13.1	12.4	13.6	13.4	14.6	N.A.	N.A.	N.A.	N.A.	dB (std dev)

When evaluating DTV service, the well-known digital cliff effect can be very *helpful* (if you are *above* threshold) and it can provide the viewer with perfect picture and sound, or it can be very *harmful* (if you are *below* threshold) and provide the viewer with nothing but blue screen, silence, and frustration. Therefore, it is good to know the percentage of test sites that have at least 10 dB of margin (some amount of safety for outdoor reception in a severe multipath environment). A severe multipath condition can cause 5 dB to 8 dB of noise threshold degradation as well as some amount of flat spectral fading as well. Therefore, 10 dB is a reasonable number to use for a *minimum* desired margin for outdoor reception. Of course, additional margin would also be desired when indoor reception is of prime importance.

From Table 13, it can be seen that with DTx *inactive*, approximately 75% - 85% of the sites (both 30' AGL and 15' AGL) had at *least* 10 dB of margin on CH 33 and CH 12. For all of the test scenarios with DTx *active* (CH 33 & CH 12, 30' or 15' AGL), the percentage of sites with greater than 10 dB of margin was greater than 83%, as would be expected and desired. Between 50% and 75% of the sites experience some margin increase. Even CH 65 provided 80% - 86% of the test sites with 10 dB of margin or better with the strategically placed low-power gap filler transmitters.

Also demonstrated in Table 13 is the fact that there are a majority of sites that had *improved* margins or *identical* margins with DTx active. However, there were definitely sites that had *reduced* margin when DTx was active, most likely due to the increased self-induced multipath from DTx. However, the resulting margin value often did not degrade significantly, and a vast majority of those sites where margins degraded still had margin values greater than 10 dB remaining, potentially still providing reliable DTV reception.

In Table 11, Table 12 and Table 13, the overall performance advantage of Rx1 over that of Rx2 can be seen. While both DTV receivers utilize 5G VSB decoders, and both have passed the stringent NTIA-required RF performance specifications for certification, it should be noted that there still can be some performance differences among the various receivers on the market. Table 11 reveals that Rx2 does not perform quite as well as Rx1 when DTx is active. Clearly, Table 12 shows that while Rx1 and Rx2 sometimes provided comparable levels of margin over large numbers of test sites, Rx2 on the average had 1 - 2 dB less margin than Rx1. Finally, Table 13 demonstrates that Rx2 provided 5% - 10% less sites that have at least 10 dB of margin. Despite these differences, Rx2 still had reasonable DTV reception in the field, and occasionally had 1 dB or 2 dB better margin than Rx1.

Therefore, while the DTx could not significantly improve outdoor DTV service at 30' AGL and 15' AGL since service was already so good, it indeed did improve site *margins*, and therefore provide for the potential of increased DTV service availability over time as conditions vary diurnally and seasonally.

Table 13 Inside the “box” DTV margin site percentages with antenna adjusted for peak signal strength.

DTx Status	CH 33				CH 12				CH 65				Units
	30'		15'		30'		15'		30'		15'		
	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	
DTx OFF (M > 10 dB)	78	76	71	69	69	69	63	63	N.A.	N.A.	N.A.	N.A.	sites
	90	90	90	90	83	83	83	83	N.A.	N.A.	N.A.	N.A.	sites, total
	86.7	84.4	78.9	76.7	83.1	83.1	75.9	75.9	N.A.	N.A.	N.A.	N.A.	%
DTx ON (M > 10 dB)	88	85	81	75	79	77	79	73	75	71	73	69	sites
	90	90	90	90	83	83	83	83	87	87	87	87	sites, total
	97.8	94.4	90.0	83.3	95.2	92.8	95.2	88.0	86.2	81.6	83.9	79.3	%
Better Margin (Δ > 0 dB)	51	51	51	44	62	61	55	54	N.A.	N.A.	N.A.	N.A.	sites
	90	90	90	90	83	83	83	83	N.A.	N.A.	N.A.	N.A.	sites, total
	56.7	56.7	56.7	48.9	74.7	73.5	66.3	65.1	N.A.	N.A.	N.A.	N.A.	%
Same Margin (Δ = 0 dB)	8	10	12	16	10	7	7	4	N.A.	N.A.	N.A.	N.A.	sites
	90	90	90	90	83	83	83	83	N.A.	N.A.	N.A.	N.A.	sites, total
	8.9	11.1	13.3	17.8	12.0	8.4	8.4	4.8	N.A.	N.A.	N.A.	N.A.	%
Worse Margin (Δ < 0 dB)	31	29	27	30	11	15	21	25	N.A.	N.A.	N.A.	N.A.	sites
	90	90	90	90	83	83	83	83	N.A.	N.A.	N.A.	N.A.	sites, total
	34.4	32.2	30.0	33.3	13.3	18.1	25.3	30.1	N.A.	N.A.	N.A.	N.A.	%
Worse Margin but OK (Δ < 0 dB) (M > 10 dB)	30	26	22	20	10	11	19	17	N.A.	N.A.	N.A.	N.A.	sites
	90	90	90	90	83	83	83	83	N.A.	N.A.	N.A.	N.A.	sites, total
	33.3	28.9	24.4	22.2	12.0	13.3	22.9	20.5	N.A.	N.A.	N.A.	N.A.	%

OUTDOOR DTx RANGE OF ROTATION EVALUATION

The last major evaluation of the DTx system performance in the Brooklyn area is the range of antenna rotation that provides successful DTV reception. By measuring at every test site the number degrees of antenna azimuth rotation that provides DTV reception, referred to as range of rotation (**ROR**), an indication can be obtained as to how easy it might be for a viewer to manually adjust an outdoor antenna when it is installed or remotely adjust it (with the aid of a rooftop rotor) after installation.

Table 14 contains the statistical data for range of rotation for all the test sites. The average range of rotation with DTx *inactive* and using a *directional* antenna is between **200 degrees – 300 degrees** for both CH 33 and CH 12 at both 30' and 15' AGL antenna heights. This is a respectable range of rotation and it indicates that there is enough signal level to be received from the side and possibly back lobes of the antenna as well as there being possibly enough signal reflection off the local urban clutter (e.g., homes, apartments, stores, water towers, etc.) to provide a decodable DTV signal. With DTx *active*, there was an interesting “mixed bag” of test results. Rx1 exhibited significant increases in range of rotation (between **20 degrees – 100 degrees**) while Rx2 did not exhibit the same significant increases (between **-10 degrees and 40 degrees**). The CH 65 DTx system provided an average range of rotation of at least **110 degrees**.

These antenna ranging results are very respectable, and allow for the *possibility* of reasonably easy and straightforward outdoor antenna adjustment. However, it must be pointed out that in some instances, it was difficult to measure the range of rotation due to *dynamic* signal conditions (e.g., nearby traffic flow, airplane flutter, etc.). Dynamics at some locations were significant and variable, which is a good reminder that this DTx field test is a *location* variability test and **NOT** a long-term *time* variability test.

Table 14 Inside the “box” DTV range of rotation statistics with antenna adjusted for *peak* signal strength.

DTx Status	CH 33				CH 12				CH 65				Units
	30'		15'		30'		15'		30'		15'		
	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	
DTx OFF	300.4	256.4	290.0	240.5	266.4	254.2	242.6	228.3	N.A.	N.A.	N.A.	N.A.	deg (ave)
	360.0	307.5	360.0	296.0	305.0	273.0	270.0	236.0	N.A.	N.A.	N.A.	N.A.	deg (med)
	107.9	124.3	115.1	134.5	107.8	110.7	121.6	119.1	N.A.	N.A.	N.A.	N.A.	deg (std dev)
DTx ON	337.0	259.0	313.5	231.9	350.1	289.5	344.6	267.8	289.8	224.1	275.8	207.0	deg (ave)
	360.0	360.0	360.0	294.0	360.0	360.0	360.0	360.0	360.0	261.0	340.0	235.0	deg (med)
	65.3	130.5	104.9	139.9	49.1	109.7	54.1	122.8	109.4	138.4	112.7	142.7	deg (std dev)
Change in ROR with DTx	36.5	2.6	23.5	-8.5	83.7	35.3	102.0	39.5	N.A.	N.A.	N.A.	N.A.	deg (ave)
	0.0	0.0	0.0	0.0	41.0	17.0	72.0	8.0	N.A.	N.A.	N.A.	N.A.	deg (med)
	118.0	171.8	132.4	169.9	106.6	130.3	116.2	162.0	N.A.	N.A.	N.A.	N.A.	deg (std dev)

Finally, it is advantageous to know the percentage of sites that had what may be called reasonably “safe” minimal range of rotation for successful DTV reception. **Table 15** contains site percentages for range of rotation. Of course, the definition of a safe value can be considered a *subjective* assessment. Therefore, a couple of adjustment range values were considered in this analysis.

For example, a large percentage of test sites (**80% - 90%**) with DTx *inactive* had at least 90 degrees of range of rotation for successful DTV reception and an even higher percentage had a smaller range of 45 degrees. However, a 90-degree range of rotation should allow a typical viewer to easily adjust an *outdoor* antenna towards the general direction of a group of transmitter antennas in an antenna “farm” (which may be on top of a large urban building or two) or towards multiple station groups of transmitters that happen to be spaced around 90 degrees apart from each other relative to a given receive site. Remember that if two groups of antennas are 90 degrees apart, pointing the antenna half-way in-between the two groups will cause only a 45-degree error for the antenna. Most outdoor antennas have at least 60-degree 3-dB beamwidths, and coupled with the strong signal levels measured in the Brooklyn area, good *outdoor* reception seems possible.

Of course, with DTx active, one would expect the range of rotation to increase. From **Table 15**, approximately **1/3 to 2/3** of the test sites experience some range of rotation *improvement* (both CH 33 and CH 12 at both 30' and 15' AGL). A fair amount of sites remained the *same* with regard to range of rotation (many of these “same-range” sites had 360-degree values for *both* DTx OFF and DTx ON conditions). Naturally, one might expect that the extra DTx-induced multipath might cause the receivers to fail for certain angular sectors and thus reduce the range of rotation. This was, in fact, the case at a number of sites (**2% - 15%** for Rx1 and **25% - 40%** for Rx2). Obviously, the data clearly shows that Rx1 had better RF performance (probably with regard to multipath) than that of Rx2. One encouraging issue regarding these reduced range-of-rotation sites is that many of these sites still had 90 degrees or more of range of antenna rotation with DTx active, meaning that their range of rotation degradation still allowed for reasonable antenna adjustment by the viewer and thus potential for successful *outdoor* DTV reception.

Table 15 Inside the “box” DTV range of rotation site percentages with antenna adjusted for peak signal strength.

DTx Status	CH 33				CH 12				CH 65				Units
	30'		15'		30'		15'		30'		15'		
	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	
DTx OFF (ROR>45 deg)	84	81	83	75	79	77	74	75	N.A.	N.A.	N.A.	N.A.	sites
	90	90	90	90	83	83	83	83	N.A.	N.A.	N.A.	N.A.	sites, total
	93.3	90.0	92.2	83.3	95.2	92.8	89.2	90.4	N.A.	N.A.	N.A.	N.A.	%
DTx OFF (ROR>90 deg)	82	76	81	72	75	75	72	72	N.A.	N.A.	N.A.	N.A.	sites
	90	90	90	90	83	83	83	83	N.A.	N.A.	N.A.	N.A.	sites, total
	91.1	84.4	90.0	80.0	90.4	90.4	86.7	86.7	N.A.	N.A.	N.A.	N.A.	%
DTx ON (ROR>45 deg)	90	82	85	77	82	78	82	76	83	74	82	68	sites
	90	90	90	90	83	83	83	83	87	87	87	87	sites, total
	100.0	91.1	94.4	85.6	98.8	94.0	98.8	91.6	95.4	85.1	94.3	78.2	%
DTx ON (ROR>90 deg)	88	77	81	68	82	75	82	72	79	64	79	61	sites
	90	90	90	90	83	83	83	83	87	87	87	87	sites, total
	97.8	85.6	90.0	75.6	98.8	90.4	98.8	86.7	90.8	73.6	90.8	70.1	%
Better ROR w/DTx (Δ > 0 deg)	30	34	27	28	49	43	51	43	N.A.	N.A.	N.A.	N.A.	sites
	90	90	90	90	83	83	83	83	N.A.	N.A.	N.A.	N.A.	sites, total
	33.3	37.8	30.0	31.1	59.0	51.8	61.4	51.8	N.A.	N.A.	N.A.	N.A.	%
Same ROR w/DTx (Δ = 0 deg)	52	24	49	26	32	19	30	14	N.A.	N.A.	N.A.	N.A.	sites
	90	90	90	90	83	83	83	83	N.A.	N.A.	N.A.	N.A.	sites, total
	57.8	26.7	54.4	28.9	38.6	22.9	36.1	16.9	N.A.	N.A.	N.A.	N.A.	%
Worse ROR (Δ < 0 deg)	8	32	14	36	2	21	2	26	N.A.	N.A.	N.A.	N.A.	sites
	90	90	90	90	83	83	83	83	N.A.	N.A.	N.A.	N.A.	sites, total
	8.9	35.6	15.6	40.0	2.4	25.3	2.4	31.3	N.A.	N.A.	N.A.	N.A.	%
Worse ROR but OK (Δ < 0 dB) (ROR>90 deg)	6	21	6	21	2	16	1	16	N.A.	N.A.	N.A.	N.A.	sites
	90	90	90	90	83	83	83	83	N.A.	N.A.	N.A.	N.A.	sites, total
	6.7	23.3	6.7	23.3	2.4	19.3	1.2	19.3	N.A.	N.A.	N.A.	N.A.	%

OUTDOOR INTERFERENCE SITES EVALUATION

The MTVA field test plan called for some small number of test sites outside the “Brooklyn box” that were predicted to possibly have self-interference. These sites were visited to evaluate any possible DTx self-interference effects since these receive areas were predicted to have relative amplitudes and delays (compared to the main ESB signal) from the multiple synchronized transmitted signals that might fall outside the cancellation delay range of a typical DTV receiver.

However, there were only 6 interference sites visited since the initial focus is “inside the box” for DTx performance. Therefore, with this small number of interference test sites, there is no statistically-relevant data to report. Nevertheless, the results from these 6 test sites generally indicated that there was no interference observed if they already had DTV reception without DTx active.

INDOOR FIELD TEST DATA ANALYSIS

INDOOR FIELD TEST OVERVIEW

While the primary interest of the MTVA field test was *indoor* reception, only 23 indoor sites were able to be visited during the field test as opposed to 109 outdoor sites. Indoor field testing has always been the most challenging type of field test to perform due to the required participation of willing volunteers opening their home to “invasion” by engineers with computers and other scientific equipment. Nevertheless, indoor testing was called for in the MTVA field test plan, and was accomplished, although on a much *smaller* scale than the outdoor testing due to practical considerations.

Since there is only a data set of 23 indoor test sites, with only 10 sites “inside the box” as desired, little meaningful statistically-relevant analysis can be performed, and widespread prediction of indoor performance is difficult at best.

However, *some* tabulation of the entire data set has been performed, while other anecdotal data analysis has been included in this report.

INDOOR FIELD STRENGTH EVALUATION

The first consideration in the performance evaluation of the DTx network is *peak* DTV field strength at each test site. The indoor antenna was first rotated to determine the angle at which the *maximum* DTV signal occurred at a given site. This was performed for each of the 6 individual test scenarios at each indoor test site. Total *average* DTV signal power (in 6 MHz) was measured at the spectrum analyzer input, and the equivalent root-mean-square (rms) field strength (in dB μ V/m) was *calculated* using the previously calibrated indoor test system net gain (in dB) from antenna output to spectrum analyzer input. The net indoor test system gain includes the short coaxial feed-line cable loss (in dB), variable attenuator loss (in dB), and preamplifier gain (in dB), plus the known antenna gain over dipole (in dBd) and the dipole conversion factor for each RF channel. Appropriate frequency-dependent parameter values were used for *each* test channel.

Indoor field strength analysis, shown in Table 16, provides some insight into the ability of the DTV signal to penetrate buildings in the New York City area. Of particular interest is the DTx *inactive* statistics for all 23 sites where the average ESB signal strength (with the dipole antenna adjusted for maximum signal level) *inside the buildings* was very respectable (about 69 dB μ V/m on CH 33 and about 51 dB μ V/m on CH 12) using a dipole antenna. Of course, there is no result for CH 65 since there was no CH 65 transmitter at ESB (i.e., no DTV inactive condition).

Some observations can be made regarding these results. The average DTV field strength on CH 33 and CH 12 with DTx *inactive* was sufficiently above the required minimal level for successful DTV reception with typical indoor receive equipment. Since most of the indoor test sites (13 out of 23) were *outside* the box, the average *increase* in the indoor field strength with DTx active was only about 4 dB (both CH 33 and CH 12).

However, when only the 10 Brooklyn “box” indoor sites are considered, the average field strength increase was noticeably greater (7 dB for CH 33 and about 9 dB for CH 12), climbing from an average of 66 dB μ V/m to 73 dB μ V/m on CH 33 and from 51 dB μ V/m to 60 dB μ V/m on CH 12. The greater *increase* (i.e., change) in field strength with DTx active for these particular 10 test sites compared to the analysis with all 23 sites is due to the fact that these 10 sites were all inside the box and therefore they all benefited from the extra gap filler transmitter signals. Also, CH 12 exhibited a larger field strength increase than CH 33 with DTx *active* for the Brooklyn “box” test sites since the temporary ESB CH 12 transmitted signal is highly directional and relatively low power unlike the commercial omni-directional, high-power CH 33 transmitter signal, and can therefore benefit more from the extra “boost” that gap filler transmitters provide. Finally, the CH 65 received signal exhibited reasonable average indoor field strengths (64 dB μ V/m with DTx active) at the 10 homes that were inside the box.

It should be noted that these results must be “taken with a grain of salt” for a couple of reasons. First, with only 23 total indoor test sites, and only 10 of them inside the box, statistical relevancy does not hold. Also, the indoor field strength values are also affected by the fact that the indoor test sites varied in height above ground level from 0’ AGL (ground level) to 60’ AGL (6th floor), i.e., they were located on a variety of different floors within the buildings where the testing was performed. Therefore, some of the indoor test sites were located *above* the outdoor 30’ AGL height. To achieve relevant statistics for field strength in the region would require significantly more indoor test sites “inside the box.”

Table 16 Indoor field strength statistics.

DTx Status	Primary Antenna			Secondary Antenna			Units
	CH 33	CH 12	CH 65	CH 33	CH 12	CH 65	
DTx OFF (all) (All 23 sites)	68.8	51.4	N.A.	65.0	49.5	N.A.	dB μ V/m (ave)
	67.7	50.2	N.A.	64.0	47.4	N.A.	dB μ V/m (med)
	9.4	7.0	N.A.	9.4	7.4	N.A.	dB μ V/m (std dev)
DTx ON (All 23 sites)	72.4	56.0	61.6	68.7	53.9	57.8	dB μ V/m (ave)
	70.4	55.5	58.4	66.7	52.5	53.8	dB μ V/m (med)
	8.6	9.7	10.2	8.6	9.7	10.9	dB μ V/m (std dev)
DTx OFF (Inside the Box) (10 sites)	66.2	51.1	N.A.	62.1	49.0	N.A.	dB μ V/m (ave)
	66.6	49.7	N.A.	61.0	46.9	N.A.	dB μ V/m (med)
	8.6	6.5	N.A.	7.5	6.5	N.A.	dB μ V/m (std dev)
DTx ON (Inside the Box) (10 sites)	72.7	60.4	68.0	70.0	58.1	65.0	dB μ V/m (ave)
	70.4	58.0	64.3	66.9	56.4	65.4	dB μ V/m (med)
	7.5	10.2	7.7	7.0	9.7	7.5	dB μ V/m (std dev)

An important aspect of the indoor field testing is the outdoor-to-indoor signal attenuation that is experienced in an urban area such as New York City. Therefore, at every indoor field test site, a companion outdoor test site measurement (referred to as a

“driveway” measurement) was performed. This provided a reference outdoor set of data to match that gathered inside the home. The primary purpose of doing this was to determine not only the attenuation that the signal experiences as it travels from outside to inside (antenna height loss and building penetration loss), but to also ascertain what typical outside signal levels are required for acceptable indoor DTV reception with and without DTx.

The field test truck was parked as close as possible to the indoor test location, often on the street right in front of the building under test and typically within 50'. However, it is well understood that outdoor signal strength variations, sometimes large due to the presence of multipath, can occur over relatively short distances. Likewise, as mentioned above, the indoor test sites were located on different floors within the building, often *higher* above the ground level than the outside measurement (15' AGL and 30' AGL). For instance, 39% (9 out of 23) sites were on floors 30' AGL or higher, and 74% (17 out of 23) were on floors 15' AGL and higher. Understandably, some of the indoor test sites exhibited quite a bit *larger* field strengths inside than outside (e.g. some sites had indoor field strength levels 10 dB – 16 dB *higher* than the 15' AGL or 30' AGL outdoor field strength levels), thereby biasing the attenuation factors much *lower* than what would be expected for typical two-story single-family (residential) homes. Therefore, the following outdoor-to-indoor attenuation data, shown in Table 17, must be put into proper perspective when analyzing the results. With this biased test situation, the typical average attenuation values from outdoor at 30' AGL to indoor were about 6 dB for CH 33, about 8.5 dB for CH 12, and 5 dB for CH 65.

Table 17 Outdoor-to-indoor field strength attenuation statistics.

DTx Status	30' AGL to Primary Antenna			15' AGL to Primary Antenna			Units
	CH 33	CH 12	CH 65	CH 33	CH 12	CH 65	
DTx OFF (All 23 sites)	5.6	7.8	N.A.	5.0	5.5	N.A.	dB (ave)
	6.6	6.3	N.A.	5.8	5.0	N.A.	dB (med)
	6.5	10.4	N.A.	7.0	8.4	N.A.	dB (std dev)
DTx ON (All 23 sites)	6.4	8.9	5.6	4.3	6.2	4.4	dB (ave)
	8.3	6.5	4.9	5.1	4.1	4.2	dB (med)
	8.8	10.0	10.3	7.9	8.7	9.2	dB (std dev)

Table 18 contains the corresponding statistical SNR values for these indoor sites. From this data, it is obvious that it is possible to provide reasonable SNR values inside the home to allow for the possibility of indoor reception without DTx. With DTx, the SNR values increase by **several dB or more**, even when including sites “outside the box,” and they increase significantly for sites “inside the box” that benefit from the multiple synchronized DTx transmitters.

Table 18 Indoor SNR statistics.

DTx Status	Primary Antenna			Secondary Antenna			Units
	CH 33	CH 12	CH 65	CH 33	CH 12	CH 65	
DTx OFF (All Sites) (All 23 sites)	37.6	30.3	N.A.	37.8	30.6	N.A.	dB (ave)
	36.9	29.0	N.A.	36.8	28.8	N.A.	dB (med)
	9.0	6.9	N.A.	8.9	7.1	N.A.	dB (std dev)
DTx ON (All Sites) (All 23 sites)	41.3	34.8	28.6	41.5	34.9	30.3	dB (ave)
	39.4	34.4	25.6	39.9	33.9	26.7	dB (med)
	8.4	9.6	10.4	8.2	9.6	11.1	dB (std dev)
DTx OFF (Inside the Box) (Only 10 sites)	35.2	30.2	N.A.	35.0	30.3	N.A.	dB (ave)
	35.5	28.7	N.A.	33.8	28.3	N.A.	dB (med)
	8.7	6.4	N.A.	7.6	6.5	N.A.	dB (std dev)
DTx ON (Inside the Box) (Only 10 sites)	41.7	39.4	35.2	43.0	39.4	37.7	dB (ave)
	39.3	37.1	31.7	39.9	37.8	38.3	dB (med)
	7.6	10.3	7.7	7.2	9.7	7.5	dB (std dev)

INDOOR SERVICE EVALUATION

During the MTVA field test, only 10 of the 23 indoor test sites could be obtained *inside* the Brooklyn “box” (as defined by the location of the 4 low-power gap filter transmitters). Therefore, a majority of the test sites (13) did not experience full (or in some cases, not even partial) benefits from the DTx network signals, and were possibly even degraded by self-interference. Therefore, complete statistical DTx service analysis on all the visited test sites (23) was *not* warranted in this case (as it was in the outdoor field testing) as it would unfairly describe the DTx system performance since the major focus of the prototype design and field test was inside the Brooklyn “box”. However, UHF CH 33 service directly from ESB (i.e., DTx *inactive*) was, in fact, analyzed and evaluated at all 23 indoor test sites since the transmitted commercial signal is operating at full power in all azimuth directions, although not with an optimum transmit antenna configuration due to the current overcrowding of antennas on the ESB mast. This specific statistical analysis provides some indication of current indoor DTV

reception from ESB on a UHF channel without DTx. The CH 12 test results for the entire 23 indoor test sites were not completely evaluated statistically due to the CH 12 transmitter with its *lower effective radiated power* and *directional transmit antenna* on ESB, nor were the CH 65 results evaluated statistically for the entire 23 indoor test sites since there was not a CH 65 transmitter on ESB (i.e., there was no “DTx inactive signal to measure”).

Using the primary UHF dipole receive antenna in each home, successful DTV reception was observed in 16 out of 23 homes (about 70%) with Rx1 and 15 out of 23 (about 65%) with Rx2, which are not bad results for using the existing single-source CH 33 ESB signal. This would indicate that, with a better transmit antenna facility on ESB, *perhaps* acceptable indoor DTV reception *might* be possible regionally.

For the *complete* evaluation of the DTx system, on the 10 Brooklyn “box” indoor test sites were considered. The results are shown in **Table 19** and **Table 20** for the primary and secondary receive antennas, respectively. While statistically not relevant due to the small number of test sites, the indoor test results do provide some indication of DTx performance benefits.

For the primary indoor receive antenna, CH 33 indoor DTV service with DTx *inactive* was reasonable (70%), and improved with DTx *active* (90%). CH 12 indoor DTV service with DTx *inactive* was very poor (20%), and only slightly increased with DTx *active* (30%). CH 65 with DTx *active* had very good indoor DTV service (90%), indicating that indoor service is possible with just four synchronized low-power gap filler transmitters.

Likewise, the indoor test results from these 10 indoor sites within the box show improvements in margin and range of antenna rotation on CH 33 and CH 12 with DTx active. Margins and range of rotation on CH 65 are also very encouraging. Also note that Rx1 once again exhibits slightly better indoor performance on the average than does Rx2.

Table 19 Primary antenna test results for the 10 “in-the-box” DTV indoor test sites

DTx Status	Test Parameter	CH 33		CH 12		CH 65		Units
		Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	
DTx OFF (10 sites)	DTV Service	70.0	60.0	20.0	10.0	N.A.	N.A.	%
	Margin	12.5	11.9	3.6	2.2	N.A.	N.A.	dB (ave)
	Range of Rotation	179.5	170.0	36.0	36.0	N.A.	N.A.	deg (ave)
DTx ON (10 sites)	DTV Service	90.0	80.0	30.0	30.0	90.0	90.0	%
	Margin	18.2	16.6	9.0	8.8	16.6	16.4	dB (ave)
	Range of Rotation	288.0	261.0	92.0	92.0	251.5	233.5	deg (ave)

The secondary (directional) receive antenna also provided similar types of results (service, margin, and range of rotation), although not quite as good as the primary (dipole) receive antenna. Obviously, range of rotation could easily be better with the primary dipole antenna since the entire “back side” of its adjustment range is the same as its “front side” due to its “figure-8” azimuth pattern that provides no front-to-back attenuation ratio. On the other hand, one might have expected that service and margin would have been slightly better with the directional antennas (some multipath mitigation due to antenna directionality) unless the equalizer hardware and control algorithm makes good use of the “extra” echoes allowed by dipole antennas to help decode the DTV signal. Of course, the downside to dipole receive antennas is that they do not isolate certain sections of the viewing room as someone walks through and possibly disrupts the propagation path (which did occur occasionally during the MTVA indoor field tests). During these dynamic situations, a receiver with a dipole antenna must almost totally depend on its equalizer for error-free reception (except for the nulls in its azimuth pattern), which is a situation where receivers can differentiate themselves in performance from others. Nevertheless, there is encouragement that acceptable indoor service *may* be possible in New York City with appropriate optimizations in both transmitter system and receiver system design.

Table 20 Secondary antenna test results for the 10 “in-the-box” DTV indoor test sites

DTx Status	Test Parameter	CH 33		CH 12		CH 65		Units
		Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	
DTx OFF (10 sites)	DTV Service	60.0	50.0	20.0	20.0	N.A.	N.A.	%
	Margin	10.1	9.4	3.9	3.8	N.A.	N.A.	dB (ave)
	Range of Rotation	144.5	138.0	30.0	30.0	N.A.	N.A.	deg (ave)
DTx ON (10 sites)	DTV Service	80.0	80.0	30.0	30.0	80.0	80.0	%
	Margin	18.6	18.3	8.6	8.1	16.1	15.8	dB (ave)
	Range of Rotation	208.5	208.5	58.0	54.0	265.5	265.5	deg (ave)

The comparison between DTx inactive and DTx active for indoor DTV reception is shown in **Table 21** for the 10 inside-the-box test sites. Each indoor test site was evaluated for DTV service, margin, and range of rotation with and without DTx, and then categorized as having either *better* performance, *same* performance, or *worse* performance with DTx. Once again, with only 10 Brooklyn “box” sites, there is not enough data to be statistically relevant, but the trends are very similar to those

found from the outdoor field testing. Note that many of the sites had good DTV reception *without* DTx, and therefore no benefit was seen in DTV service. However, the margin and range of rotation was improved at a large percentage of sites, particularly for Rx1. These results also show that while the margin was sometimes reduced when DTx was active, some of these “degraded” sites still had more than 10 dB of margin (i.e., the “worse, but OK” description). It can also be seen from these results that DTx did not perform as well on CH 12 as it did on CH 33.

Table 21 Comparison test results for the 10 “inside the box” indoor test sites for CH 33 and CH 12.

Parameter	Comparison (10 sites)	Primary Antenna				Secondary Antenna				Units
		CH 33		CH 12		CH 33		CH 12		
		Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	Rx1	Rx2	
Service	Better	30	40	20	20	30	40	20	20	%
Service	Same	60	40	70	80	60	50	70	70	%
Service	Worse	10	20	10	0	10	10	10	10	%
Margin	Better	60	50	20	20	60	60	30	20	%
Margin	Same	0	10	60	70	10	10	60	60	%
Margin	Worse	40	40	20	10	30	30	10	20	%
Margin	Worse, but OK	30	20	10	10	20	20	0	10	%
ROR	Better	50	50	20	20	40	40	20	20	%
ROR	Same	30	30	80	80	30	30	60	60	%
ROR	Worse	20	20	0	0	30	30	20	20	%
ROR	Worse, but OK	0	0	0	0	0	0	0	0	%

As part of the indoor DTV reception testing, a smart antenna was evaluated at *each* house, and for *each* receiver since this technology is expected to be available to consumers in the near future. The same smart antenna was used (sequentially) with each DTV receiver in order to minimize the number of test variables and thus keep the comparisons straightforward. The first step was to perform a channel scan with the receiver, letting it find as many DTV stations as it could, automatically optimizing the antenna for the best receive conditions. Once the scan was completed, which took noticeably *longer* than a normal scan without the smart antenna, and the received channels were stored in the receiver’s channel memory, the tester sequentially selected the three desired DTV test channels to evaluate reception.

The smart antenna was found to generally work when the manually adjusted antennas succeeded, and it generally did not work when the manually-adjusted antennas failed. With all the scenarios (three RF channels, two types of receive antennas, and DTx active and inactive), the smart antenna mimicked the manually-adjusted antenna in terms of DTV service almost 90% of the time. The other 10% of the time, the smart antenna split almost in half the number of times it was better than the manually-adjusted antenna and the times that it was worse.

While the smart antenna did *not* make much of an improvement, it essentially did not make matters worse, and it did provide *automatic* antenna adjustment (appreciated by most viewers, especially the “couch potatoes”), although at the cost of an increased channel scan time. It should be noted, however, that the smart antenna algorithms in these very early generation of smart controllers *apparently* do not constantly update the antenna optimization, nor is updating done when there is a channel change. Consequently, these primitive algorithms do not attempt to correct for quickly changing propagation effects (from dynamic conditions *outside* the home or movement of people *inside* the home) nor does it attempt to update its parameters for even slowly changing propagation effects (unless a manual scan is performed). Perhaps new algorithms may account for these types of changes in future products.

ANECDOTAL DTx OBSERVATIONS

During any type of field testing, there are often important observations made regarding the received signal and the conditions surrounding it, and these observations go a long way to help further understand RF propagation phenomenon in the real world. The MTVA New York City field test was no exception. The following material summarizes some of these observations, particularly with regard to DTV propagation in a major urban area and the effects of a DTx system. *Twelve* examples are briefly described, along with plots from a small number of the many (over 14,000) data files that were captured and archived as part of the MTVA DTx field test in New York City.

These examples are taken from a *variety* of test sites with varying propagation conditions, and include data from all three RF test channels (CH 33, CH 12, CH 65), both outdoor receive antenna height conditions (30’ AGL and 15’ AGL), and both indoor receive antenna types. All of these examples describe the system performance in field conditions that existed when the DTx network was *active* rather than inactive. Using the active DTx condition (rather than DTx inactive) simultaneously serves two purposes: (1) it shows the measurement results of two or more synchronized transmitters in a single frequency

network, and (2) it still demonstrates the naturally-occurring multipath in a large urban area that each individual transmitter signal experiences. The primary purpose of these examples is to demonstrate some of the various propagation conditions that were encountered in the field, which will give broadcast engineers a better understanding of real-world conditions and their effect on urban DTV reception and distributed transmission.

Each of the examples described below refers to a *pair* of plots (contained in **Figure 8** through **Figure 19**), one showing the DTV signal spectrum at the time of the test and the other showing a TxID of the propagation channel impulse response (CIR) as measured using the RF watermark TxID test signal that was inserted 30 dB below the 6 MHz DTV signal. The spectrum analyzer plots display the desired DTV test channel on a 20 MHz span so that the first upper and lower adjacent channel is shown. The TxID analyzer plots are *not* the ones that were seen by the testers on site, but rather they are Excel plots that were created with a comma separated variable (CSV) file that was obtained from the TxID's control program. Each vertical line represents the relative *amplitude* and *delay* of an individual signal propagation path. Note that the horizontal linear time delay scale for these TxID plots varies from example to example in order to best illustrate the different field conditions that were encountered. Also note that the vertical logarithmic scale has a maximum value of 0 dB (i.e., the largest received signal is defined as 0 dB and all the others are considered pre-echoes and post-echoes below this reference). The minimum value is -10 dB (which removes the sometimes-confusing noise-like data results from the RF watermark cross-correlation process). See Appendix 1 for more background information on the RF Watermark ID process.

The various curves on the TxID plots represent the different transmitter signals received at the give test site, and all have the same legend definitions:

- Curve A = Gap Filler Transmitter #1 = **Blue Diamond** (16 Court Street)
- Curve B = Gap Filler Transmitter #2 = **Lavender Square** (95 Evergreen)
- Curve C = Gap Filler Transmitter #3 = **Orange Triangle** (730 Linden)
- Curve D = Gap Filler Transmitter #4 = **Turquoise "X"** (Bishop Ford High School)
- Curve E = ESB Transmitter = **Purple Circle** (Empire State Building)

It is important to remember that, while the spectrum analyzer and Tx ID analyzer plots are very helpful in determining *static* conditions at a given test site, *dynamic* conditions are not represented in these plots and these dynamic conditions may have significant effects on DTV reception. On-site expert observers often provide additional valuable information that may further help in assigning the cause of DTV reception problems in the field.

Each example in the text below describes the test site name and type as well as the base file name from which the spectrum and TxID plots were generated. The DTV signal attributes are also included (channel number, field strength, and SNR) as well as the signal multipath conditions. Note that the largest transmitter signal that was received is identified in the examples, and is called the main signal. All other transmitter signals are referred to as DTx-induced *multipath* since all the DTx transmitters are synchronized so that identical signals are transmitted from all the transmitters. However, each type of signal (main or otherwise) can have its own self-induced (i.e., naturally occurring) multipath, and they are identified as such. Remember that all of these echoes (pre- or post-, naturally-occurring or DTx-induced) act like static multipath to the DTV equalizer due to DTx synchronization. The description of the echo amplitude A_E (i.e., the strength) uses the following guidelines:

- Very Strong: $-1 \text{ dB} \leq A_E$
- Strong: $-3 \text{ dB} \leq A_E < -1 \text{ dB}$
- Moderate: $-7 \text{ dB} \leq A_E < -3 \text{ dB}$
- Weak: $A_E < -7 \text{ dB}$

The examples are numbered consecutively from 1 through 12.

Example 1: Reference Plot: **Figure 8**

Test Site:	B54	File - 15-HD-011-T5-12	Driveway test site, 15' AGL
Signal attributes:	CH 12	Field Strength = 41.1 dB μ V/m	SNR = 20.0 dB
Largest signal:	Tx E (minimal multipath)		
DTx signals:	Tx A = -3.8 dB @ +20.8 μ secs (minimal multipath)		
DTV reception:	Rx1 service - No;	Rx1 margin = 0 dB	
	Rx2 service - No;	Rx2 margin = 0 dB	
Comments:	A strong, long, DTx-induced <i>post</i> -echo plus a relatively weak signal (SNR= 20 dB) probably caused lack of service. Flat amplitude spectrum occurred since the strong multipath echo is so long that multiple ripples fell within resolution bandwidth of the spectrum analyzer and are averaged out.		

Example 2: Reference Plot Figure 9

Test Site: IN-7 File – S-HI-007-T5-33 Indoor test site, secondary antenna
 Signal attributes: CH 33 Field Strength = 59.1 dB μ V/m SNR = 32.1 dB
 Largest signal: Tx E (strong, short post-echo)
 DTx signals: Tx D = -0.6 dB @ -20.4 μ secs (minimal multipath)
 Tx A = -9.8 dB @ - 7.8 μ secs (minimal multipath)
 DTV reception: Rx1 service - No; Rx1 margin = 0 dB
 Rx2 service - No; Rx2 margin = 0 dB
 Comments: The very strong, long, DTx-induced *pre*-echo despite a relatively strong signal (SNR> 30 dB) probably caused lack of service. The short echo caused the 4-dB ripple across the 6 MHz DTV signal spectrum.

Example 3: Reference Plot Figure 10

Test Site: IN-7 File – S-HI-007-T5-12 Indoor test site, secondary antenna
 Signal attributes: CH 12 Field Strength = 42.7 dB μ V/m SNR = 24.0 dB
 Largest signal: Tx D (2 moderate short post-echo & 1 moderate short pre-echo)
 DTx signals: Tx E = -3.5 dB @ +15.8 μ secs (1strong, 1 moderate, & 1weak short pre-echoes)
 Tx A = -3.7 dB @ +15.2 μ secs (1 strong short & 1 weak short pre-echoes)
 DTV reception: Rx1 service - No; Rx1 margin = 0 dB
 Rx2 service - No; Rx2 margin = 0 dB
 Comments: The two very strong, long, DTx-induced *post*-echoes plus their own strong pre-echoes, despite a moderately strong signal (SNR> 32 dB), probably caused lack of service. The very short naturally-occurring post-echo caused the 2-dB upwards tilt across the 6 MHz DTV signal spectrum, while the strong DTx-induced echoes are so long that multiple ripples fell within resolution bandwidth of the spectrum analyzer and are averaged out.

Example 4: Reference Plot Figure 11

Test Site: A10 File – 30-G1-009-T5-33 Outdoor grid test site, 30' AGL
 Signal attributes: CH 33 Field Strength = 70.5 dB μ V/m SNR = 41.9 dB
 Largest signal: Tx E (minimal multipath)
 DTx signals: Tx A = -3.3 dB @ -18.2 μ secs (many strong, pre- and post-echoes)
 DTV reception: Rx1 service - Yes; Rx1 margin = 11 dB
 Rx2 service - No; Rx2 margin = 0 dB
 Comments: The strong, long, DTx-induced pre-echo plus its own multiple pre-and post echoes, despite a very strong signal (SNR> 40 dB), probably caused lack of service in Rx2. However, Rx1 was able to handle this condition, and demonstrates differing RF performance between various 5G VSB decoders. The strong DTx-induced pre-echoes are so long that multiple ripples fell within resolution bandwidth of the spectrum analyzer and are averaged out.

Example 5: Reference Plot Figure 12

Test Site: A33 File – 30-G1-061-T4-65 Outdoor grid test site, 30' AGL
 Signal attributes: CH 65 Field Strength = 64.5 dB μ V/m SNR = 32.2 dB
 Largest signal: Tx C (weak short post-echo)
 DTx signals: Tx D = -2.7 dB @ -1.2 μ secs (moderate, short post-echo)
 DTV reception: Rx1 service - Yes; Rx1 margin = 9 dB
 Rx2 service - No; Rx2 margin = 0 dB

Comments: The strong, long, DTx-induced *pre*-echo plus its own pre-and post echoes, despite a very strong signal (SNR > 40 dB), probably caused a lack of service in Rx2. However, Rx1 was able to handle this condition, and demonstrates differing RF performance between various 5G VSB decoders. The strong (-2.7 dB), short (1.2 µsecs) DTx-induced echo caused the large (dominant) 10 -15 dB amplitude ripples on the DTV spectrum.

Example 6: Reference Plot Figure 13

Test Site: B8 File – 30-G1-051-T4-65 Outdoor grid test site, 30' AGL

Signal attributes: CH 65 Field Strength = 71.4 dBµV/m SNR = 37.3 dB

Largest signal: Tx A (1 moderate & 2 weak short post-echoes & 1 moderate short pre-echo)

DTx signals: Tx B = -3.1 dB @ +3.5 µsecs (minimal multipath)

DTV reception: Rx1 service - Yes; Rx1 margin = 14 dB
Rx2 service - No; Rx2 margin = 0 dB

Comments: The strong, DTx-induced *post*-echo, despite a very strong signal (SNR > 30 dB), probably caused a lack of service in Rx2. However, Rx1 was able to handle this condition, and demonstrates another example of differing RF performance between various 5G receivers. The short pre- and post-echoes of the main signal caused the combination of low-frequency ripple and downward tilt of the spectrum. The strong (-3.1 dB), longer (+3.5 µsecs), DTx-induced echo caused the higher frequency amplitude ripples on the DTV spectrum.

Example 7: Reference Plot Figure 14

Test Site: B8 File – 30-G1-051-T5-33 Outdoor grid test site, 30' AGL

Signal attributes: CH 33 Field Strength = 75.0 dBµV/m SNR = 45.2 dB

Largest signal: Tx E (1 very strong, short pre-echo)

DTx signals: Tx B = -1.3 dB @ -2.1 µsecs (minimal multipath)

Tx A = -4.0 dB @ -6.2 µsecs (1 very strong short pre-echo & 1 moderate short post-echo)

DTV reception: Rx1 service - Yes; Rx1 margin = 20 dB
Rx2 service - Yes; Rx2 margin = 17 dB

Comments: Despite the one very strong, DTx-induced short *pre*-echo and a strong self-induced, short *pre*-echo, both receivers were able to provide DTV service with good margins (although there was a 3 dB difference in the margins). The short naturally-occurring pre-echo caused the spectrum dip in the middle of the channel.

Example 8: Reference Plot Figure 15

Test Site: B8 File – 30-G1-051-T5-12 Outdoor grid test site, 30' AGL

Signal attributes: CH 12 Field Strength = 63.0 dBµV/m SNR = 41.8 dB

Largest signal: Tx A (1 very strong, short post-echo, 2 weak short pre-echoes)

DTx signals: Tx E = -0.2 dB @ -0.2 µsecs (1 strong post-echo, 1 weak short pre-echo)

Tx B = -7.9 dB @ -1.8 µsecs (2 very strong post-echoes)

DTV reception: Rx1 service - Yes; Rx1 margin = 14 dB
Rx2 service - Yes; Rx2 margin = 12 dB

Comments: Despite the one very strong (-0.2), DTx-induced, short *pre*-echo and a strong, naturally-occurring *post*-echo on the main signal, both receivers were able to provide DTV service with good margins. The very strong, DTx-induced, short pre-echo and the strong short, post-echo on the main signal caused the spectrum tilt at both ends of the RF channel.

Example 9: Reference Plot: Figure 16

Test Site: A5 File – 15-G1-023-T5-12 Outdoor grid test site, 15' AGL

Signal attributes: CH 12 Field Strength = 62.4 dBµV/m SNR = 48.7 dB

Largest signal: Tx A (1 weak short pre-echo)
 DTx signals: Tx E = -0.5 dB @ -3.7 μ secs (1 moderate pre-echo)
 DTV reception: Rx1 service - Yes; Rx1 margin = 20 dB
 Rx2 service - Yes; Rx2 margin = 11 dB
 Comments: Despite the one very strong (-0.5 dB), DTx-induced *pre*-echo, both receivers were able to provide DTV service with good margins (however, the RF performance difference between the two receivers is seen once again in the margins). With no strong very short echoes, the spectrum remained flat, with the long, strong, DTx-induced echo causing higher-frequency ripple in the spectrum.

Example 10: Reference Plot: Figure 17

Test Site: IN-21 File – P-HI-021-T5-33 Indoor test site, Primary antenna
 Signal attributes: CH 33 Field Strength = 71.5 dB μ V/m SNR = 39.9 dB
 Largest signal: Tx E (1 weak short pre-echo, 1 moderate short post-echo)
 DTx signals: Tx A = -2.7 dB @ -8.4 μ secs (minimal multipath)
 DTV reception: Rx1 service - Yes; Rx1 margin = 19 dB
 Rx2 service - Yes; Rx2 margin = 19 dB
 Comments: Despite the one strong (-2.7 dB), DTx-induced *pre*-echo, both receivers were able to provide DTV service with good margins (and equivalent performance). The short pre- and post-echoes caused a slight spectrum “bowing” across the band, and the longer DTx-induced echo that causes higher-frequency ripple in the spectrum was averaged out by the spectrum analyzer’s RBW filter.

Example 11: Reference Plot: Figure 18

Test Site: A5 File – 15-G1-023-T5-33 Outdoor test site, 15' AGL
 Signal attributes: CH 33 Field Strength = 72.4 dB μ V/m SNR = 44.0 dB
 Largest signal: Tx E (1 weak pre-echo, 1 weak post-echo)
 DTx signals: Tx A = -1.2 dB @ -4.1 μ secs (minimal multipath)
 DTV reception: Rx1 service - Yes; Rx1 margin = 19 dB
 Rx2 service - Yes; Rx2 margin = 20 dB
 Comments: This is a relatively clean site in terms of naturally-occurring multipath. Despite the one very strong (-1.2 dB), DTx-induced *pre*-echo, both receivers were able to provide DTV service with good margins (and approximately equivalent performance). With no strong short echoes, the spectrum was reasonably flat, and the strong, long, DTx-induced pre-echo caused the higher-frequency ripple in the spectrum.

Example 12: Reference Plot: Figure 19

Test Site: A2 File – 30-G1-001-T5-12 Outdoor test site, 30' AGL
 Signal attributes: CH 12 Field Strength = 73.3 dB μ V/m SNR = 54.3 dB
 Largest signal: Tx E (1 weak short post-echo)
 DTx signals: Tx A = -3.0 dB @ +3.3 μ secs (1 moderate short pre-echo, 3 moderate post-echoes)
 DTV reception: Rx1 service - Yes; Rx1 margin = 32 dB
 Rx2 service - Yes; Rx2 margin = 31 dB
 Comments: Despite the one strong (-3.0 dB) DTx-induced post-echo, both receivers were able to provide DTV service with very good margins (and approximately equivalent performance). With no significant short echoes, the spectrum is reasonably flat, and the strong, long, DTx-induced echo caused the higher-frequency ripple in the spectrum.

SUMMARY

Distributed transmission for DTV signals has been proposed and standardized by the ATSC. The MTVA New York City field test has allowed the evaluation of the effectiveness of such a DTx system in a major urban area in both the UHF and high-VHF bands, and it has resulted in some much-needed information and experience. Knowledge and understanding of DTx fundamentals, as they apply to the ATSC transmission system, are essential for future DTx success. The MTVA small-scale prototype system in New York City optimized as many of the design parameters as possible, with the goal to ascertain the DTx system's effectiveness in providing this metropolitan area with acceptable outdoor and indoor DTV field strength levels, service, and margin, as well as ease of antenna adjustment. However, great care was taken to minimize any significant interference into existing analog or digital television signals. DTx networks in mountainous areas, while also important, do not have quite the same significant challenges that a major metropolitan area like New York City has, since urban areas potentially experience severe DTx-induced multipath (caused by multiple same-frequency synchronized transmitters) as well as considerable naturally-occurring multipath (caused by large buildings and other man-made structures).

The CH 33 *outdoor* field strength measurements at the 90 test sites within the Brooklyn "box" indicated that there were fairly consistent DTV field strength levels when the directional receive antenna angle was selected for *maximum* signal level at 30' AGL and 15' AGL. Throughout the Brooklyn "box," CH 33 DTV signals were found to be, on the average, in the range of **73 dBμV/m** (DTx OFF) to **80 dBμV/m** (DTx ON) for a 30' AGL receive antenna and they were about **3 dB** lower (DTx OFF and DTx ON) at 15' AGL. These CH 33 signal levels were not only large enough to produce SNR values (**>40 dB** for DTx OFF and **>47 dB** for DTx ON) at the receiver inputs that were above the required 15-dB white-noise threshold, but they also easily covered an additional 5 dB to 8 dB of possible noise threshold degradation due to the presence of naturally-occurring or DTx-induced multipath. The CH 33 outdoor DTV service numbers increased a modest amount from about **81%** (without DTx) to more than **85%** (with DTx). Also, significant margin and range of antenna rotation were observed at many test sites, providing *evidence* for successful long-term DTV service (i.e., accounting for signal level time variability) on CH 33.

Similarly, the CH 12 *outdoor* antenna-maximized field strength values were found to range between **59 dBμV/m** (DTx OFF) to **70 dBμV/m** (DTx ON) at 30' AGL, and they were about **2.5 dB** lower (DTx OFF and DTx ON) at 15' AGL, both producing a very high average SNR value. The CH 12 outdoor DTV service numbers increased a modest amount from about **75%** (DTx OFF) to **80%** (DTx ON), and significant margin and range of antenna rotation were likewise observed. This provided *evidence* for successful long-term DTV reception on CH 12.

Finally, the CH 65 *outdoor* results with DTx active (since there was no CH 65 ESB transmitter, this was the only mode possible to test) showed that the average field strength was a strong **76 dBμV/m** at 30' AGL and **2 dB** less at 15' AGL, and produced SNR values in excess of **40 dB**. The CH 65 DTV service was a significant **94%** (Rx) and **85%** (Rx2), with respectable margins around **20 dB**. This provided *evidence* for successful long-term DTV service on CH 65.

While the main goal of the MTVA project was to study the performance of a scaled-down version of a widespread DTx design, an added benefit was the determination that the current commercial UHF CH 33 (WPIX) single source on ESB already provided reasonably good DTV *service* in the Brooklyn test "box." In other words, the actual measured *outdoor* and *indoor* DTV *service* numbers in the field test "box" from ESB alone (i.e., DTx *inactive*) were found to be good. Of course, this means that there could not be a significant increase in the number of sites serviced with DTx active. However, despite the modest service increases due to DTx, the increase in the margin and range of antenna rotation at many sites was *encouraging*. It should be noted that DTx did, in fact, cause loss of DTV service at a small percentage of sites. Nevertheless, there were many other sites where the DTx-induced degradation of margin or range of rotation still provided acceptable DTV reception conditions.

Even though there were not enough *indoor* test sites within the DTx "box" for statistical relevancy, the 23 indoor test sites did provide field strength results on CH 33 that showed similar trends as the outdoor results. For the existing WPIX CH 33 commercial station operating at full allocated DTV power, with its partially-obstructed "omni-directional" antenna on ESB, the average indoor field strength value with DTx *inactive* for all 23 indoor test sites (including those *outside* the "box") was **69 dBμV/m**. This is a very respectable number for the average *indoor* field strength value in the New York City metropolitan area, providing an average SNR value of **38 dB** for CH 33. These 23 sites with DTx *inactive* exhibited good service (**70%** for Rx1 and **65%** for Rx2), with good margin and range of antenna rotation. Note that CH 12 and CH 65 were *not* analyzed with DTx *inactive* for indoor field strength using all 23 indoor test sites since (1) the CH 12 ESB transmit antenna was not omni-directional but rather directional, specifically pointing towards the Brooklyn "box," and (2) there was no CH 65 transmitter on ESB.

Analysis of all 23 indoor sites and their companion outdoor driveway sites showed that the signal attenuation experienced from outdoor to indoor averaged around **6 dB** for CH 33, which is much lower than the traditionally-presumed 10-dB to 20-dB values for two-story single-dwelling residences. However, this is partially explained by the fact that many of the 23 indoor test sites were *above* 15' AGL, and some were even above 30' AGL (i.e., test sites located on upper stories of

buildings that were higher than the outdoor antenna heights used in the field test). Therefore, these attenuation results must be viewed under these special circumstances.

While all 23 indoor (and driveway) test sites were used in the CH 33 DTx-*inactive* analysis, DTx system evaluation was performed on *only* the 10 indoor test sites within the Brooklyn “box.” The reason for this is that the other test sites (i.e., “outside-the-box”) did *not* gain much benefit (and perhaps even experienced detrimental *self*-interference effects) from the DTx gap-filler transmitters. Any analysis that would have included the 13 “outside-the-box” test sites would have unfairly biased the results negatively for DTx evaluation since the DTx prototype test system was specifically designed to study its performance inside the Brooklyn “box.”

For DTx *inactive*, the indoor field strengths at these 10 Brooklyn “box” test sites were approximately 66 dB μ V/m (CH 33) and 51 dB μ V/m (CH 12). These are very respectable field strength numbers for indoor DTV sites *without* benefit of DTx gap filler transmitters. Indoor DTV reception measurements resulted in about 65% (CH 33) and 15% (CH 12) service and average margins of 12 dB (CH 33) and 3 dB (CH 12).

For DTx *active*, the indoor field strengths at these 10 Brooklyn “box” test sites increased by about 7 dB (CH 33) and 9 dB (CH 12), meaning that these 10 sites exhibited average field strengths of about 73 dB μ V/m (CH 33) and 60 dB μ V/m (CH 12). Indoor DTV service increased to 85% (CH 33) and 30% (CH 12) of the test sites and the average margins were found to increase to approximately 17 dB (CH 33) and 9 dB (CH 12). As a comparison, the average CH 65 field strength with DTx active was about 65 dB μ V/m, with 90% DTV service and an average margin of 16 dB. The difference in performance between CH 33 and CH 12 is not entirely understood at this time.

An interesting side note is that the secondary *directional* indoor test antennas, which also performed well, did not do quite as well as the primary *dipole* indoor test antennas (with their figure-8 azimuth pattern). This indicates that *perhaps* the recent receiver equalizer innovations and updated algorithms now use the echoes of the signal (which typically occur more often with dipole antennas that have no front-to-back attenuation) for mitigating the multipath effect.

It is clear, however, that DTx can help DTV reception indoors, and that its negative self-interference effects can be minimized with good DTx system design as well as good receive system design.

The two 5G DTV receivers (Rx1 and Rx2) both did well in these field tests, and are significantly better than past generations. However, it was clear that Rx1 consistently did better than Rx2 in providing service, margin, and range of rotation. While both units were 5G, Rx1's multipath equalizer apparently is a little more robust, being able to handle slightly stronger and more dynamic multipath conditions than Rx2.

It must be remembered, however, that these DTx tests in New York City were *location* variability tests and *not* time variability tests. That is, the dynamic conditions that were encountered at many of the tests sites could become worse at certain times of the day (diurnal, such as with temperature changes that cause atmospheric inversion layers or with increased traffic flow at rush hour) and times of the year (seasonal, such as with and without foliage). Therefore, care must be taken when attempting to predict future widespread DTV service using short-term testing data on a small-scale prototype system. Long-term time-variability testing would certainly produce some of these answers.

A major outcome of the field test was the *experience* gained from designing, implementing, and testing a DTx system in a major metropolitan area. However, it is also important before deployment of any large communication network to determine the primary causes of DTV reception failure in order to better understand how to optimally design and construct a larger and improved *final* DTx network in New York City in time for the February 17, 2009 end of the *full-service* DTV transition. The resulting data from this field test will help future designers to achieve optimum DTx system designs.

Finally, consumer education regarding the retirement of the NTSC analog service is essential for the successful transition to over-the-air digital broadcast television. However, not only is it important to inform the public about the timing of the analog shutoff on February 17, 2009 and how to obtain NTIA converter coupons, but it is also vital to educate them about the “lost art” of over-the-air television reception. In addition to various DTV receivers, this includes the various types of receive support (accessory) equipment at their disposal, such as antennas, preamplifiers, coaxial cable, signal splitters, band splitters, attenuator pads, etc. It is likely that, even with DTx deployed in some form, successful DTV reception in New York City may depend on viewers having *reasonable* receive equipment properly installed in their homes. In order for broadcasters to successfully educate the public on DTV receive equipment and its proper use, they must first educate themselves regarding DTV reception in general (with or without DTx), and then familiarize themselves with high-quality consumer devices that are currently available.

REFERENCES

- 1 **“ATSC Field Test Vehicle Design Information”**, Gary Sgrignoli, DTV Station Project, RF Working Group, November 20, 2000.
- 2 **“Field Test Results of the Grand Alliance HDTV Transmission Subsystem”**, Charlotte Field Test Plan, submitted to SS/WP2 Field Testing Task Force of the Advisory Committee on Advanced Television Service of the Federal Communications Commission by the Association for Maximum Service Television, Inc., Cable Television Laboratories, Inc., and Public Broadcasting Service, September 16, 1994.
- 3 **“DTV Station Project General Field Test Plan for Digital Television Propagation”**, DTV Station Project, RF Working Group, November 20.
- 4 **“DTV Station Project Indoor Test Plan for Digital Television Propagation”**, DV Station Project, RF Working Group, November 20.
- 5 **“Developing DTV Field Test Plans”**, ATSC Recommended Practice A/75, July 26, 2001, www.atsc.org.

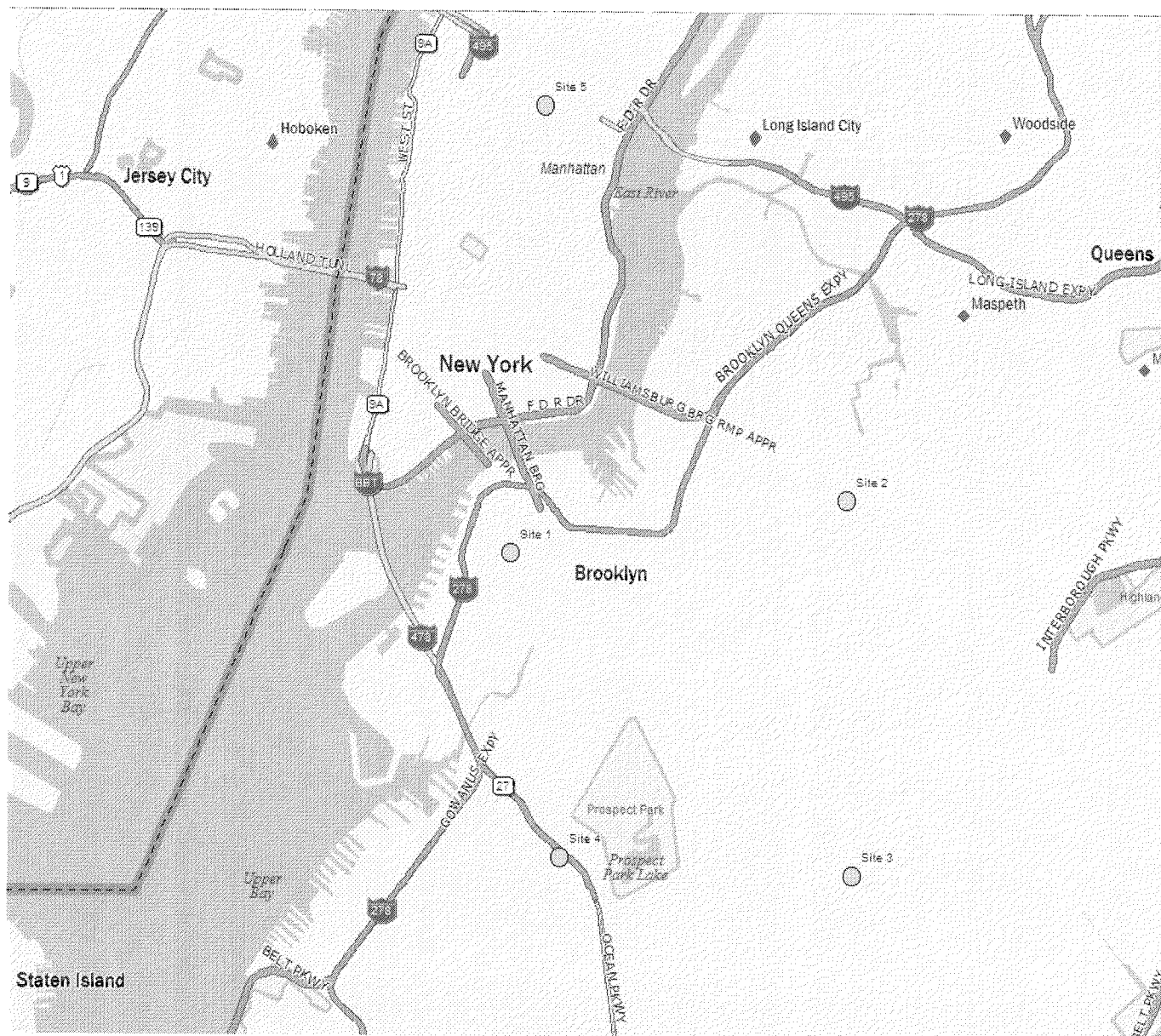
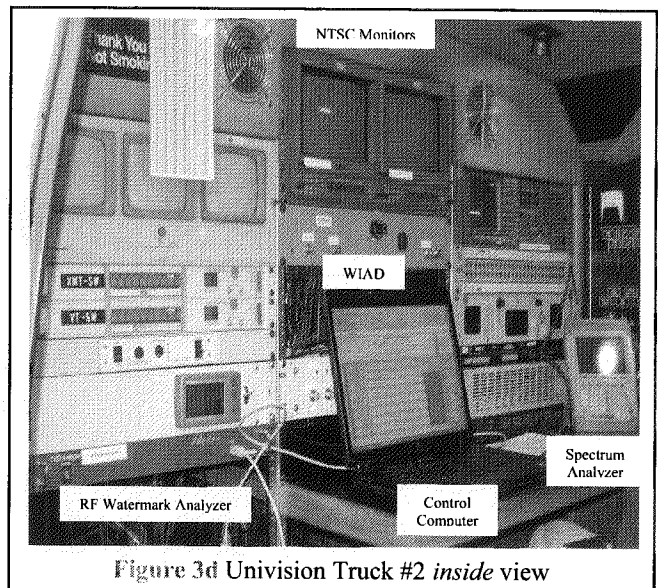
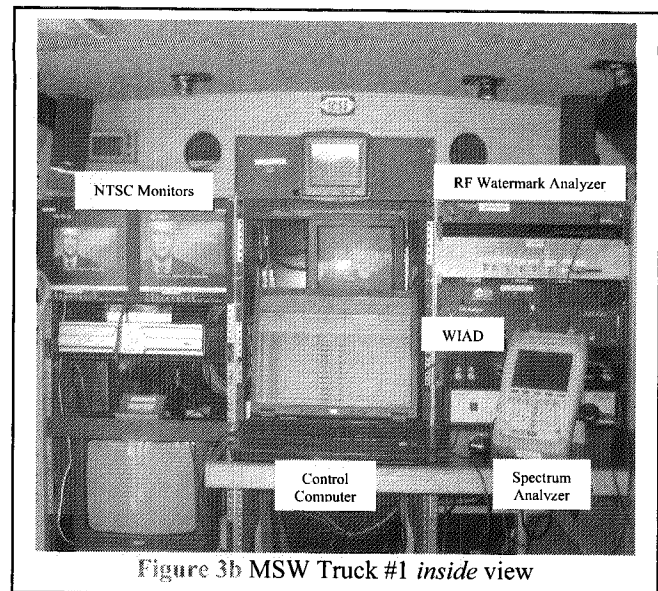
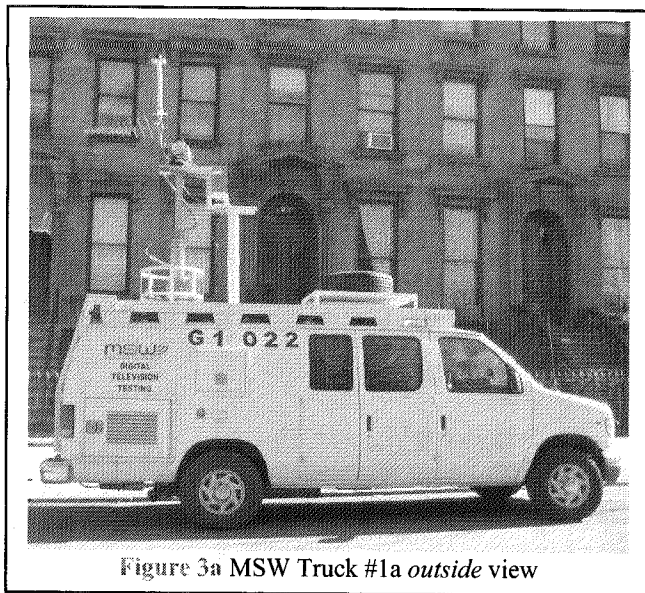
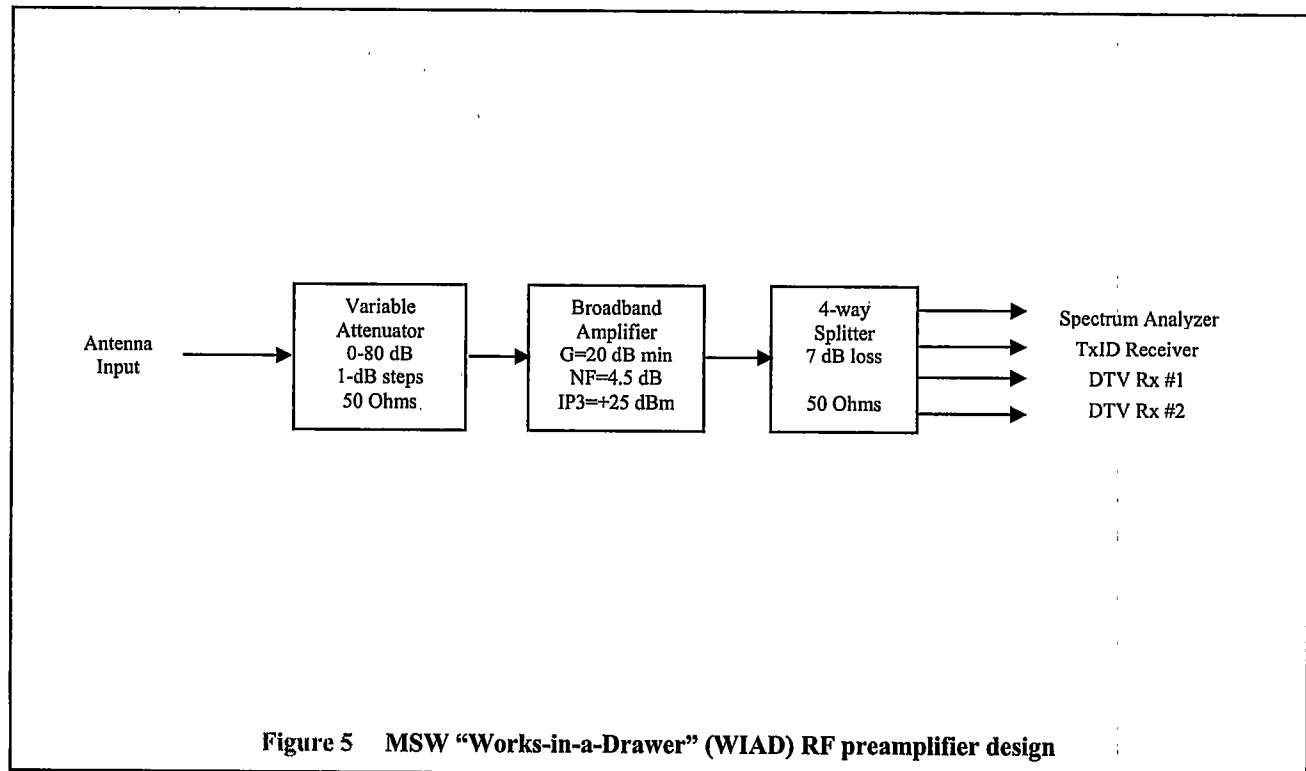
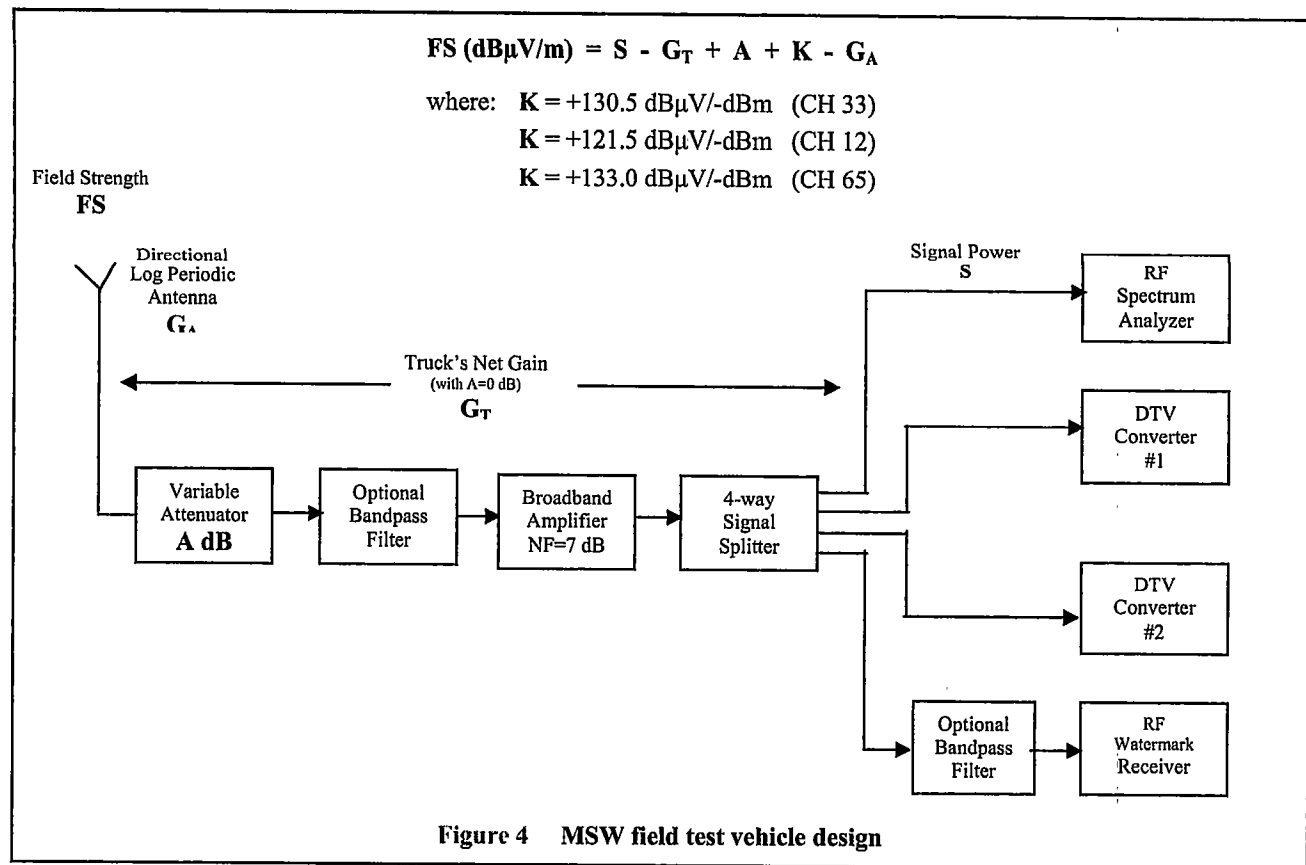
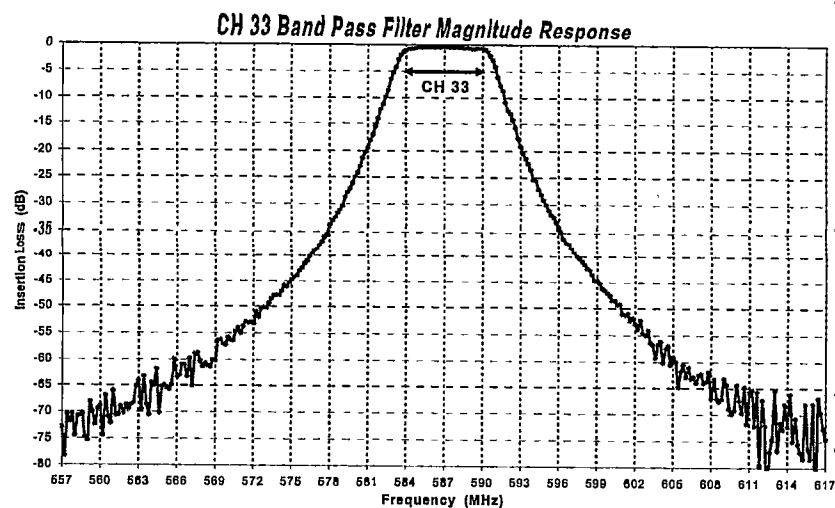
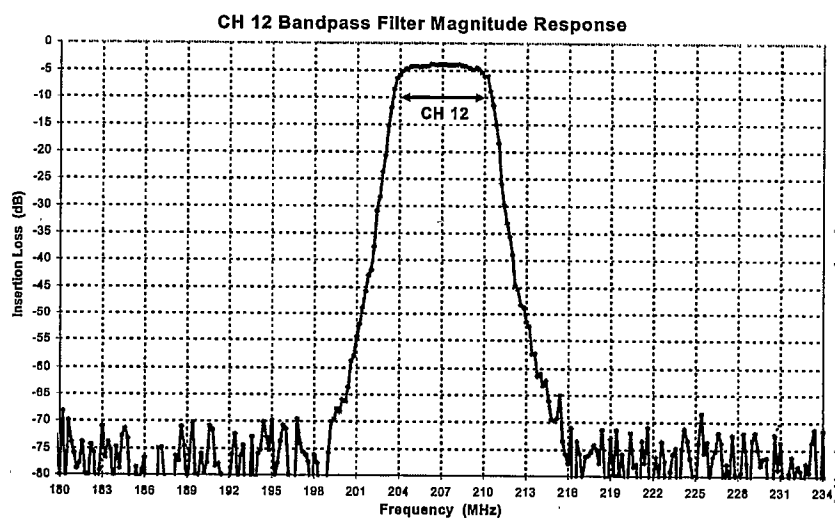
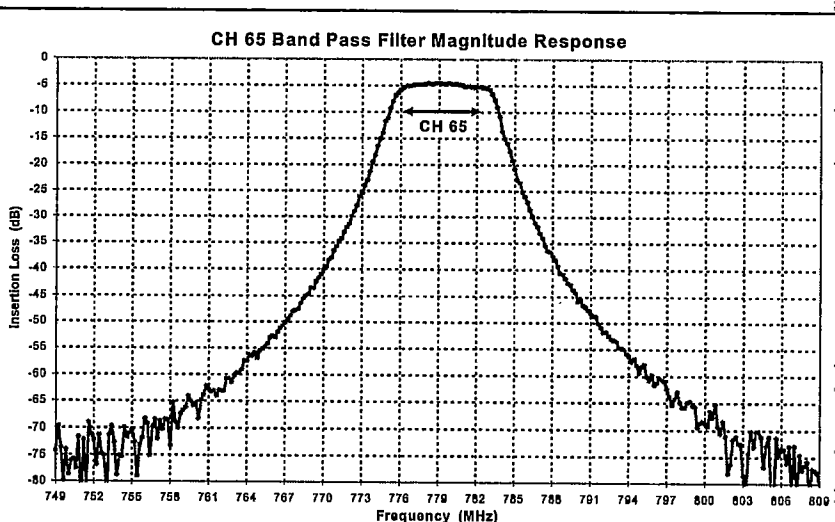


Figure 2 MTVA DTx transmitter sites (5 BLUE circles).





**Figure 6a CH 33 (587 MHz) bandpass filter magnitude response****Figure 6b CH 12 (207 MHz) bandpass filter magnitude response****Figure 6c CH 65 (779 MHz) bandpass filter magnitude response**

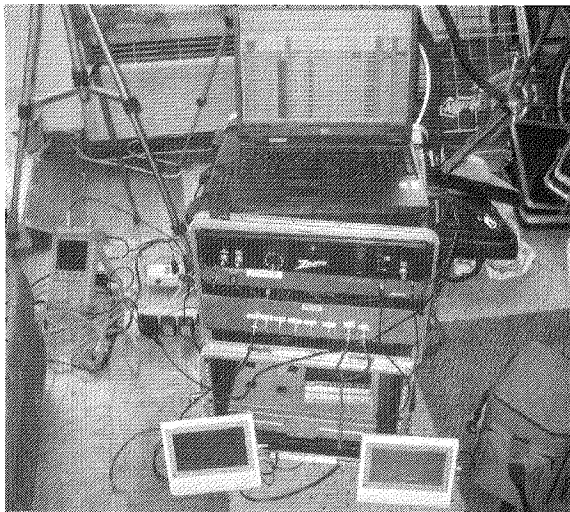


Figure 7a Indoor rack system

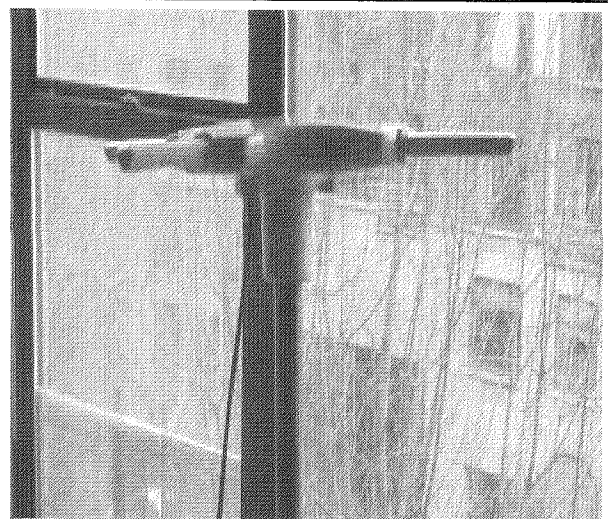


Figure 7b Smart Antenna



Figure 7c Calibrated VHF dipole antenna



Figure 7d Calibrated UHF dipole antenna

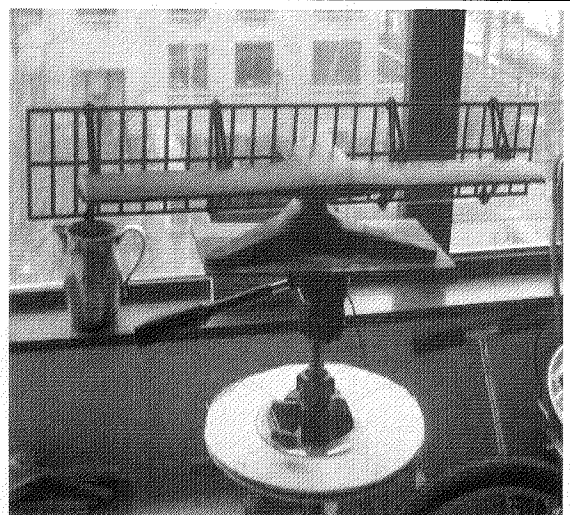


Figure 7e Sharpshooter VHF antenna

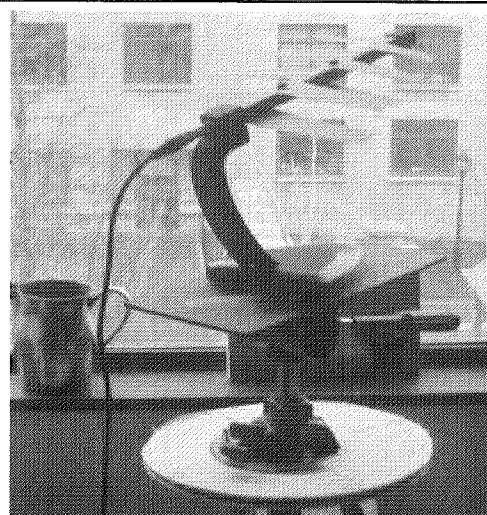
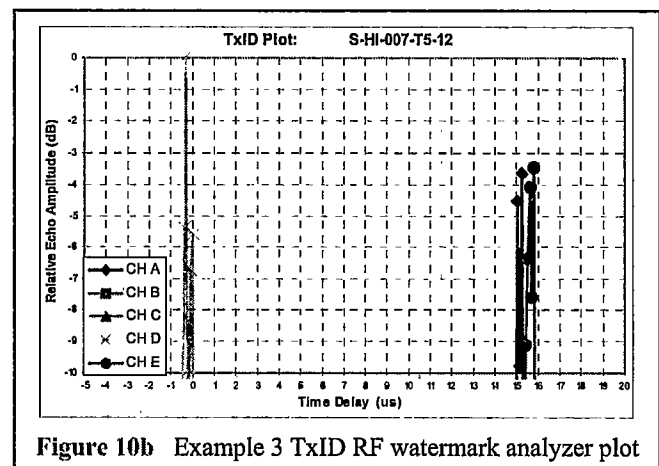
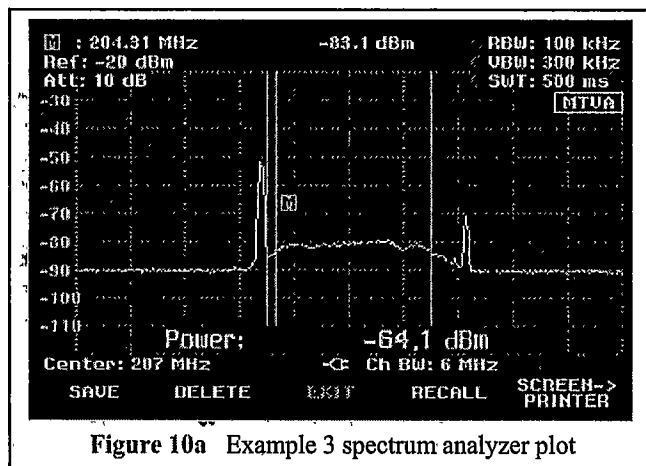
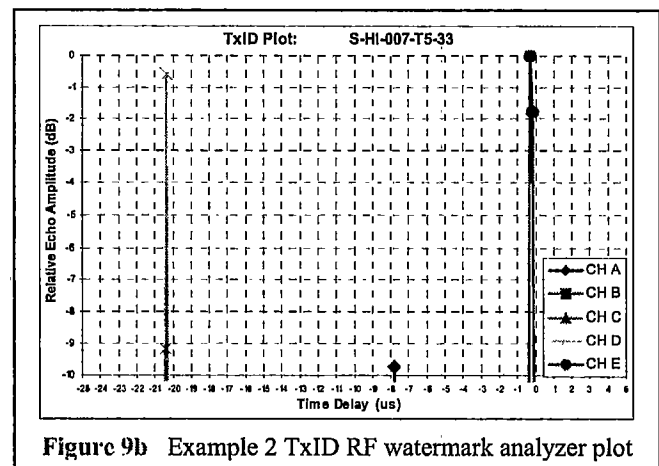
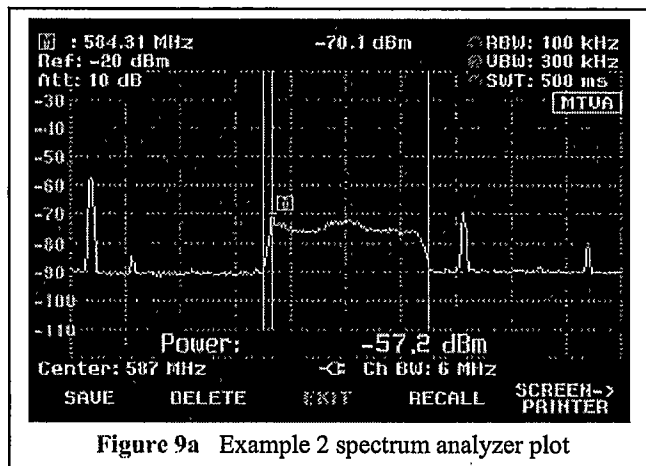
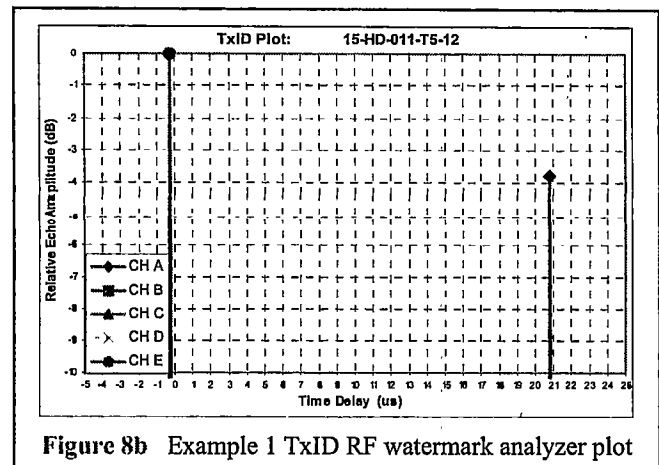
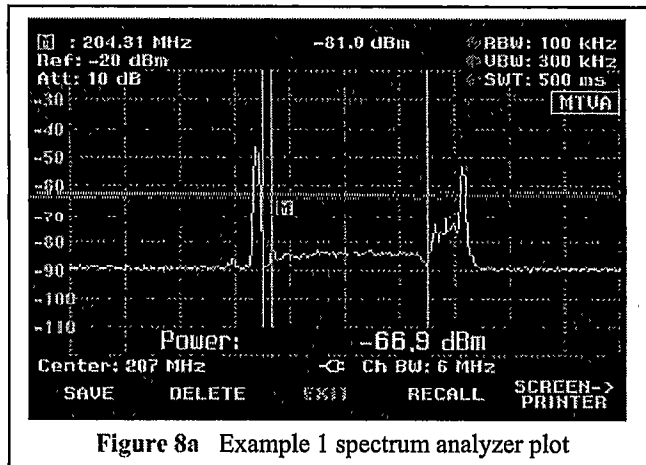


Figure 7f Silver Sensor UHF antenna



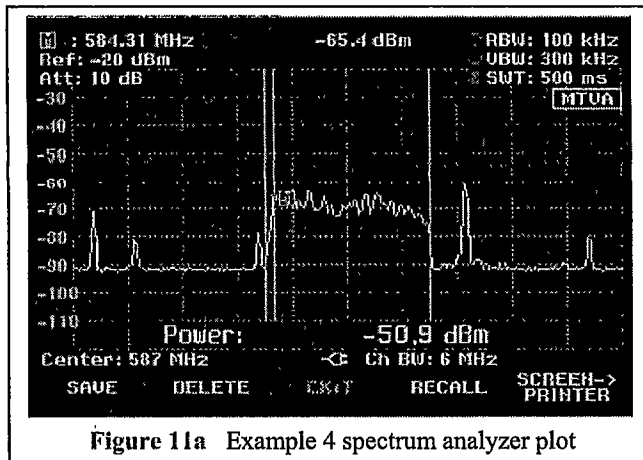


Figure 11a Example 4 spectrum analyzer plot

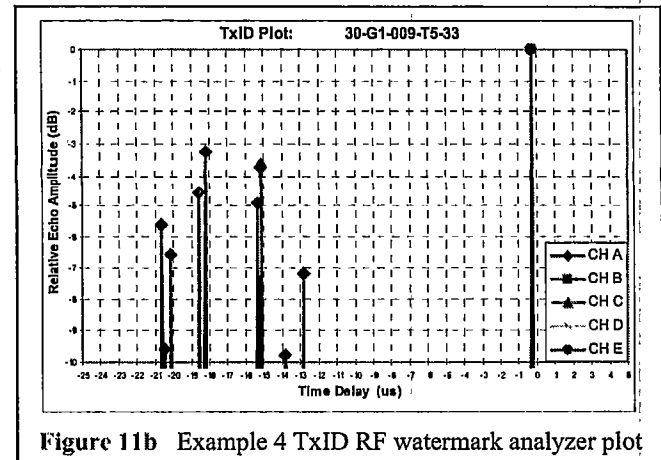


Figure 11b Example 4 TxID RF watermark analyzer plot

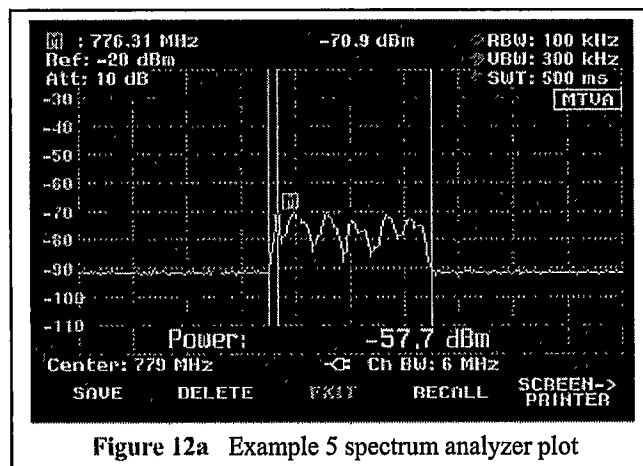


Figure 12a Example 5 spectrum analyzer plot

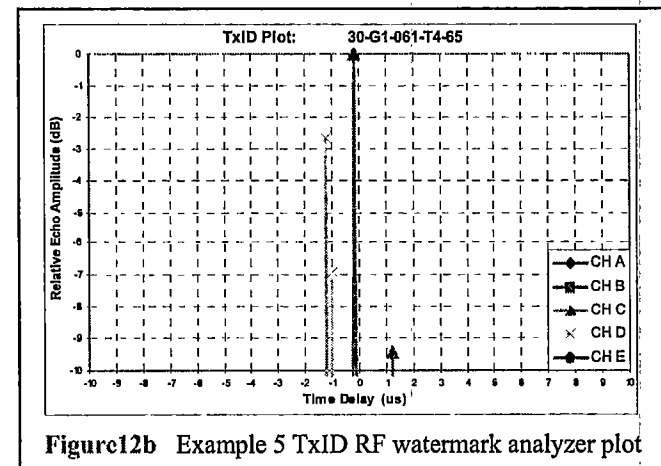


Figure 12b Example 5 TxID RF watermark analyzer plot

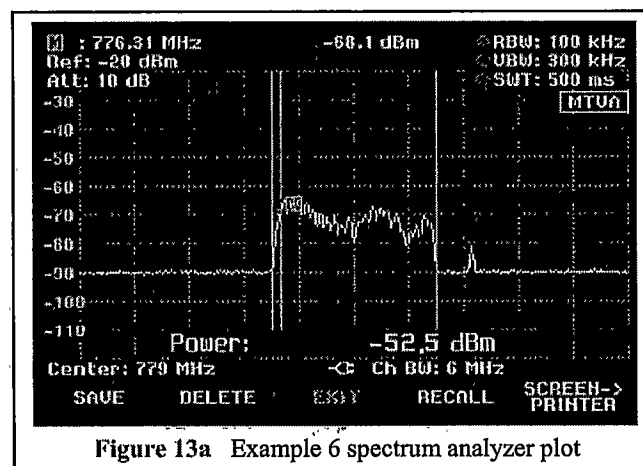


Figure 13a Example 6 spectrum analyzer plot

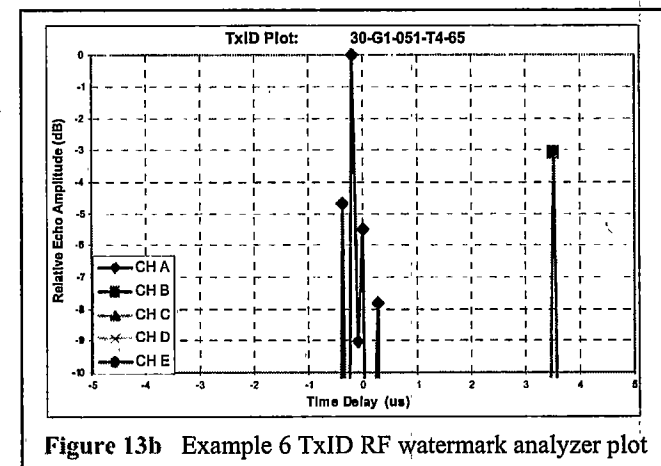


Figure 13b Example 6 TxID RF watermark analyzer plot